Multidisciplinary Design Optimization Methods for Performance and/or Cost Optimization of Vehicles

Undersea Weapon Simulation-Based Design Workshop
June 7-9, 2000

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Multidisciplinary Optimization Branch

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(http://fmad-www.larc.nasa.gov/mdob/MDOB/)

***Old Dominion University**

Outline

- **Multidisciplinary Analysis of a High-Speed Civil Transport**
  - **Background**
  - **Integration Framework**
  - **Sample of Engineering Results**
  - **Current Developments**
- **Cost-Performance Optimization of an Aircraft Wing**
  - **Process-based Cost Model**
  - **Preliminary Results for Cost Optimization**

High Speed Civil Transport

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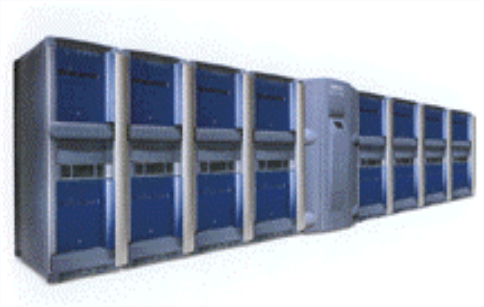
Background

1992 NASA LaRC decisions:

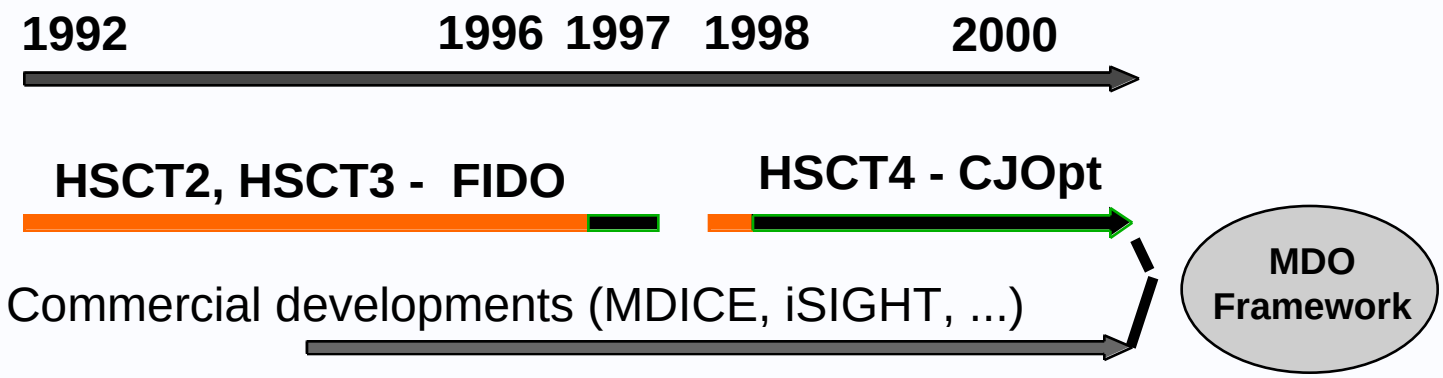
- **Began research in Multidisciplinary Design Optimization (MDO) with high-fidelity analysis codes**
  - **Exploit High Performance Computing and Communication (HPCC) as Grand Challenge application focus**
- **Selected High Speed Civil Transport (HSCT) as focus application**
  - **Exploit synergy with the High Speed Research (HSR) program**



By 2000:

- **Wrap-up of the HSCT4.0 application**
  - **Research endeavor in both MDO and HPCC**
  - **Unique combination of disciplinary breadth and depth in MDO research**

Framework History



% effort devoted to framework related issues
% effort available for application

FIDO : **F**ramework for **I**nterdisciplinary **D**esign **O**ptimization
CJOpt: **C**ORBA - **J**ava **Opt**imization

CJOpt Building Blocks

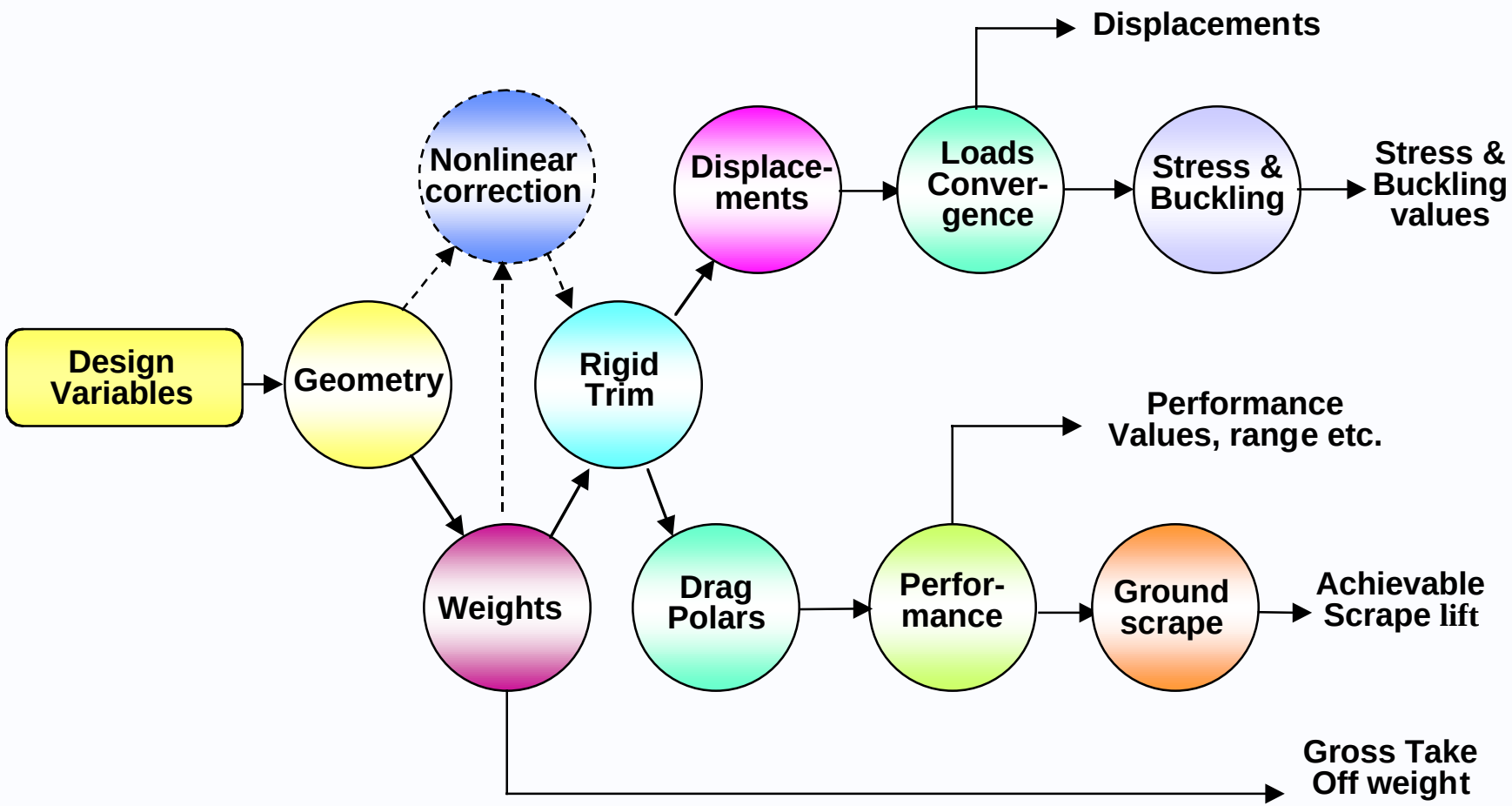
- **Common Object Request Broker Architecture (CORBA)**
- **Java Language and APIs**
- **SQL compliant database (miniSQL)**
  - **Central relational database**
  - **Commercial SQL-compliance**
  - **Objects use Java Data Base Connectivity (JDBC)**
  - **User-specific tables for transient data**
  - **File management information stored in database**

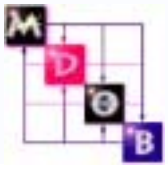
HSCT Application History

Application	HSCT2 (1994 – 96)	HSCT3 (1995 – 97)	HSCT4 (1997 – 2000)
Design Variables	5	7	271
Constraints	6	6	31868
Major Legacy Code Complexity	Low	Low-medium	Medium-high
Analysis Processes (without looping)	10	20	70
Major Processes	Weight Conv., Trim	Weight Conv., Aeroelastic, Trim	Loads Conv., Trim, Performance
Load conditions	2	2	8
Mission conditions	1	1	10
Process (with loops)	O(10)	O(100)	O(1000)
Total time	O(minutes)	O(hours)	O(1 day)

HSCT4 Analysis Flow Diagram

Fully Integrated in Object-Oriented Framework





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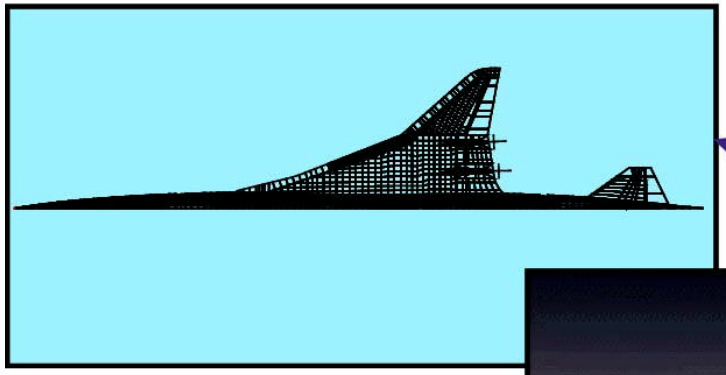
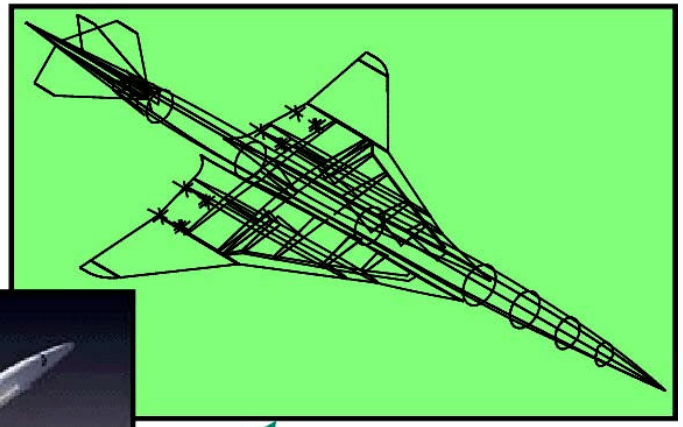
HSCT4 Analysis Features

- **Structures:**
  - Finite Element Method (GENESIS), ~40,000 DOF
- **Aerodynamics:**
  - Linear aero (USSAERO) ~ 1100 surface grid points
- **Nonlinear Aerodynamics:**
  - Euler/N-S (CFL3D), NL corrections, Volume grid ~600,000 points
- **Weight/Performance:**
  - Mission analysis and Database (FLOPS)
- **Design Variables:**
  - 244 Structural and 27 Geometric Shapes
- **Constraints:**
  - Performance, Weights, Buckling, Stress & Geometry ~ 30,000 @8 load conditions

Geometry Models for a High Speed Civil Transport



Structures

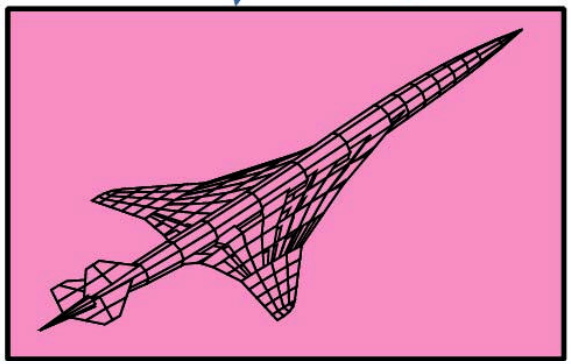


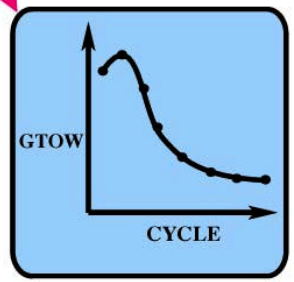
Performance

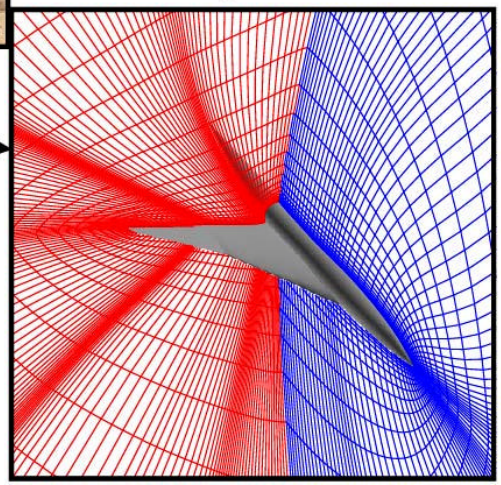
Flutter

Aerodynamics

Optimizer



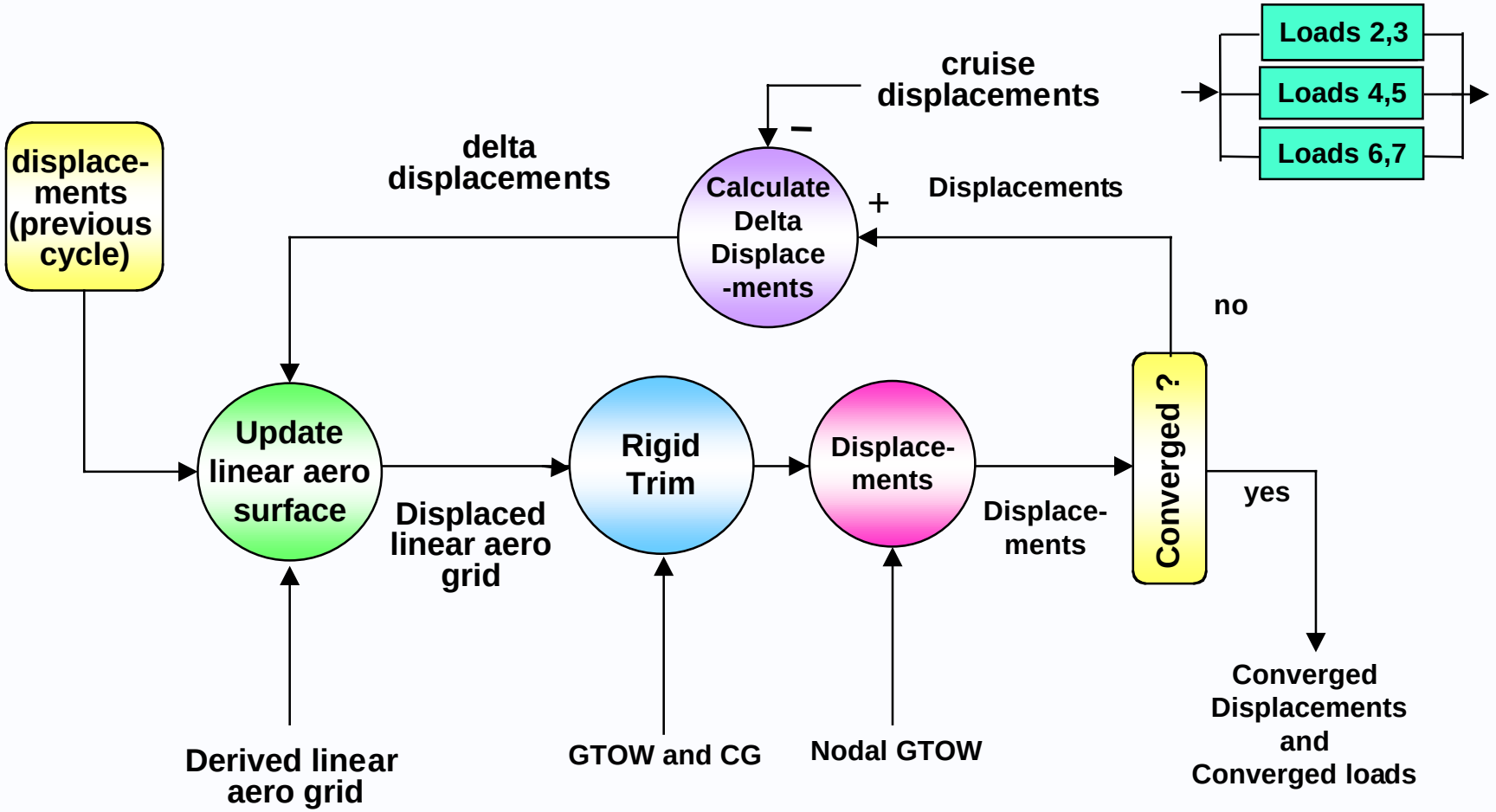




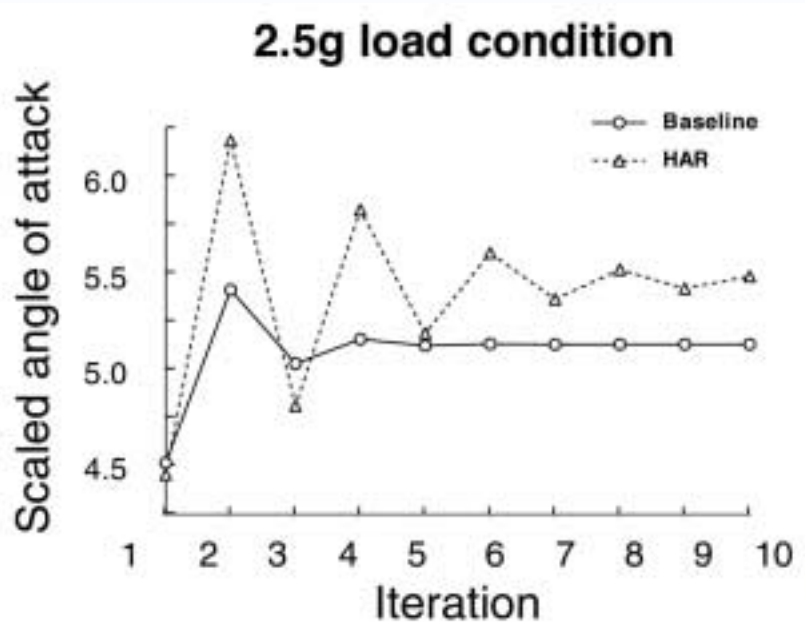
Loads Conver-gence

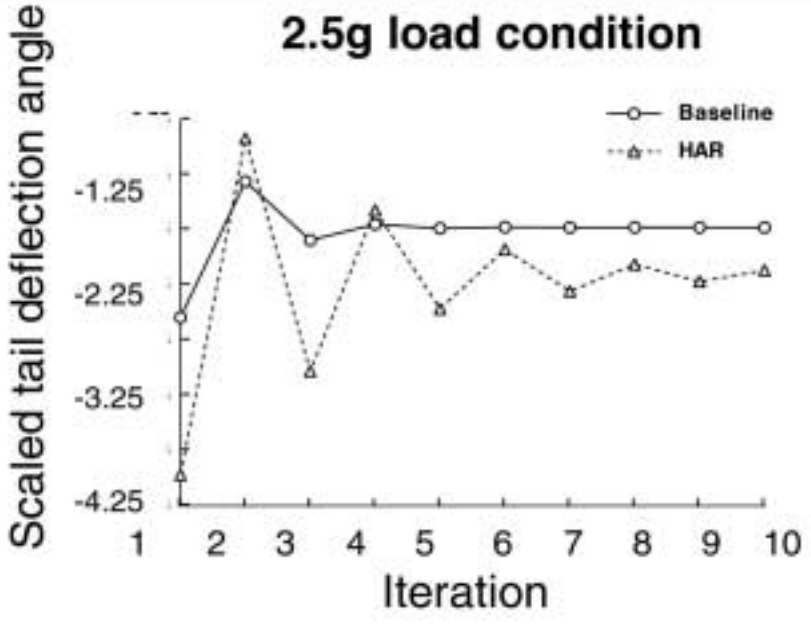
Loads Convergence Process

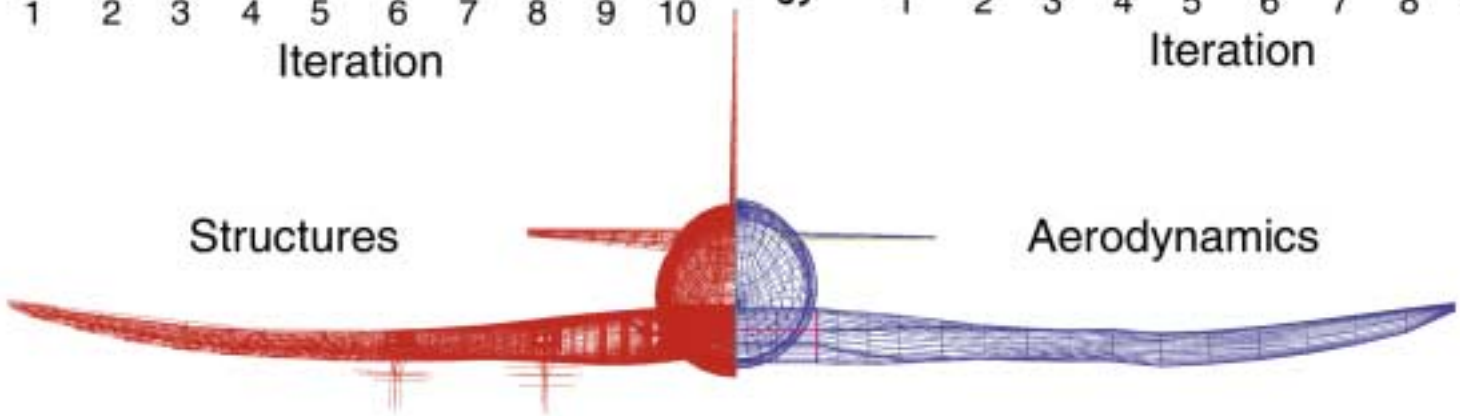
(Aeroelastic Analysis at 6 Load conditions)



HSCT4 Loads Convergence Results



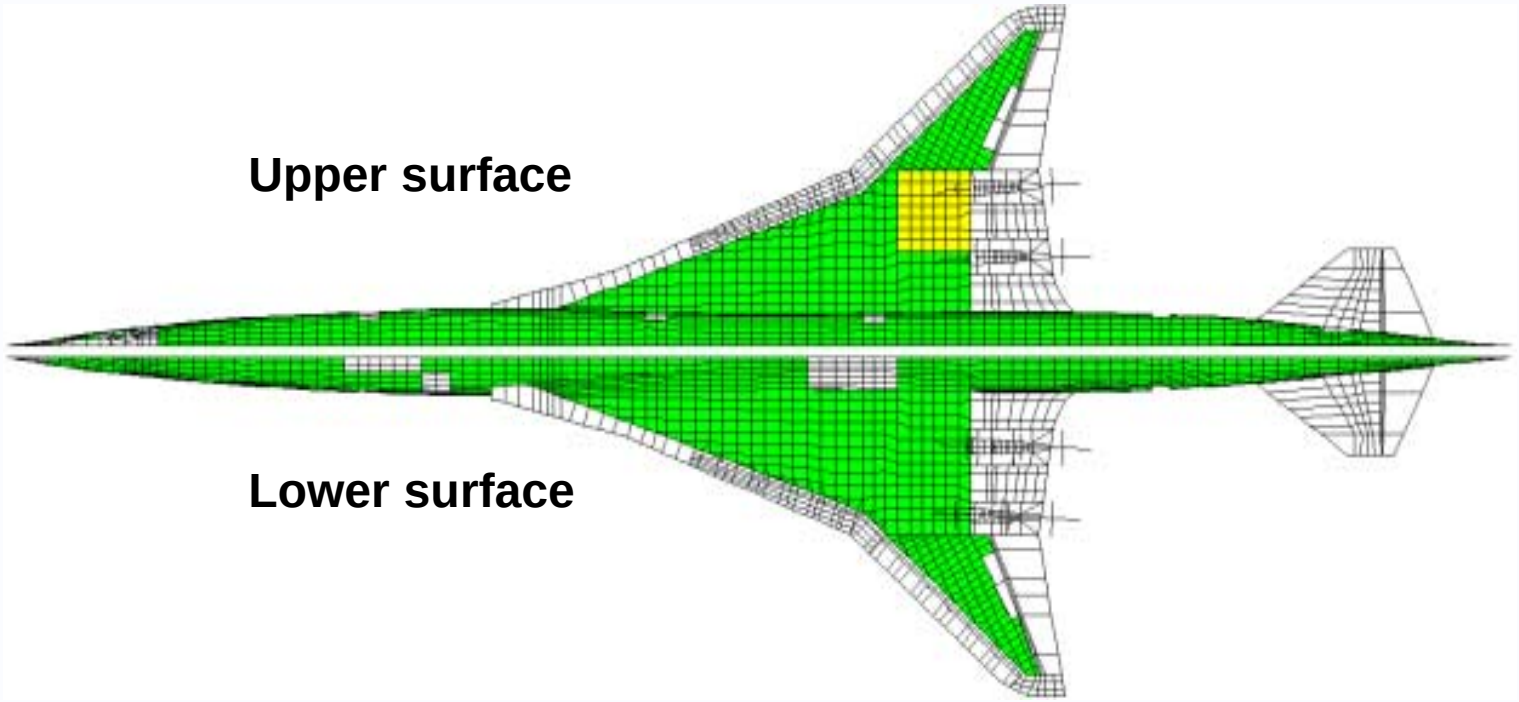




Stress & Buckling

Stress Failure Index Results

baseline, @2.5g (sample)



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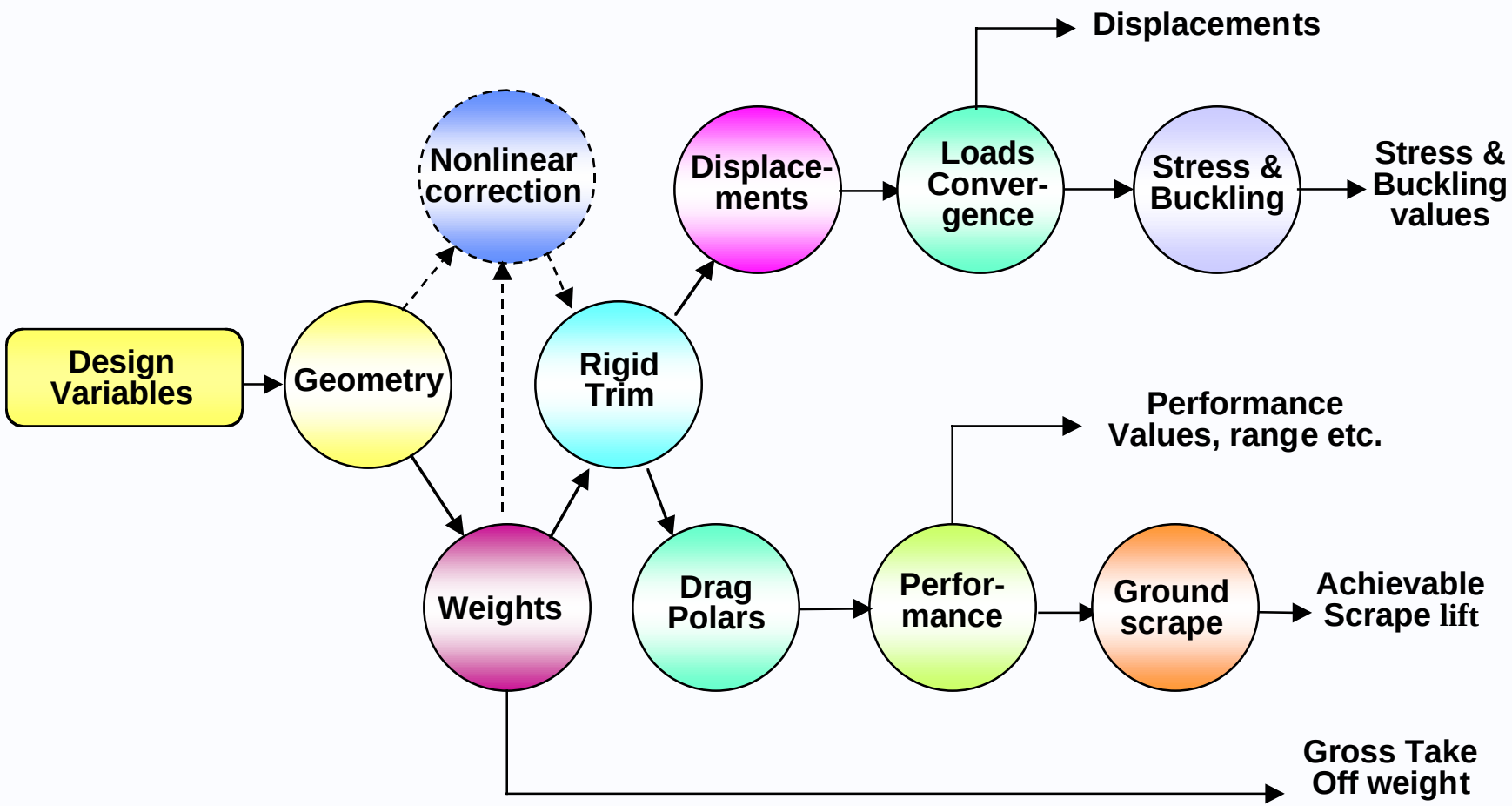
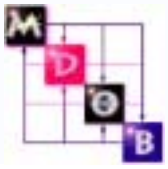
HSCT4 Analysis Flow Diagram

Fully Integrated in Object-Oriented Framework





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Typical Mission Profile

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HSCT4 Status

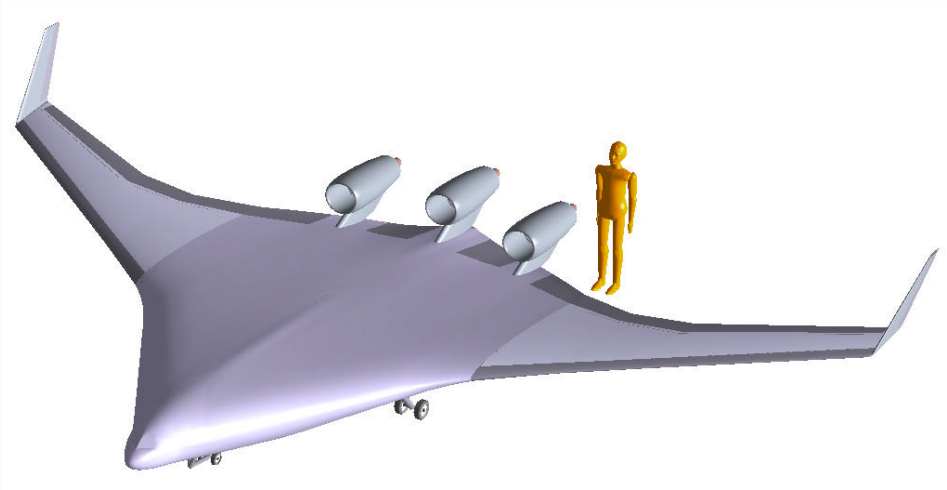
- **Multidisciplinary analysis, but not multidisciplinary optimization, has been demonstrated**
- **Detailed documentation will be available by 9/00**
  - **Requirements Document**
  - **Design Document**
  - **User's Guide**
  - **detailed process descriptions**
  - **component codes reside in a formal software configuration management system**
- **The results will be revalidated once all the minor inconsistencies discovered during detailed documentation have been remedied**
- **The HSCT application per se has been terminated because of the cancellation of HSR**

Future Developments

- **The HPCC program has shifted its applications focus to a Reusable Launch Vehicle**
  - **This is currently in the problem formulation/requirements phase**
  - **The various technical, software engineering, team dynamics, and management lessons learned from the 8 years of the HSCT application are being applied**
- **Aircraft applications using the tools developed for HSCT are continuing under the Aerospace Technologies Base program**
  - **Current focus is aerodynamics/structures/electromagnetics analysis and optimization of the Blended Wing Body**
  - **The next application is to the Joined Wing Demonstrator — a NASA/Navy/Boeing project under the REVCON program**

Current Applications

Blended Wing Body (low-speed model)



Joined Wing Demonstrator (wind tunnel model)

HSCT4 Team

CAS	MDOB	ACMB	CMSB	CSC
Sobieski, J.	Walsh, J.	Mason, B.	Biedron, R.	Sistla, R.
Rehder, J.	Weston, R.			Dovi, A.
Giunta, A.	Samareh, J.			Su, P.
	Green, L.			Shan, R.
	Salas, A.			Murthy, T.
	Townsend, J.			
	Barthelemy, J-F.			
	Mukhopadhyay, V			

HSCT4 Publications

- **Framework**
  - **R. Sistla, A. R. Dovi, P. Su,. and R. Shanmugasundaram, "Aircraft Design Problem Implementation Under the Common Object Request Broker Architecture," AIAA 99-1348**
- **Application**
  - **J. L. Walsh, J. C. Townsend, A. O. Salas, J. A. Samareh, V. Mukhopadhyay, and J.-F. Barthelemy, "Multidisciplinary High-fidelity Analysis and Optimization of Aerospace Vehicles, Part 1: Formulation," AIAA 2000-0418**
  - **J. L. Walsh, R. P. Weston, J. A. Samareh, B. H. Mason, L. L. Green, and R. T. Biedron, "Multidisciplinary High-fidelity Analysis and Optimization of Aerospace Vehicles, Part 2: Preliminary Results," AIAA 2000-0419**
- **Software Engineering**
  - **J. C. Townsend, A. O. Salas, and M. P. Schuler, "Configuration Management of an Optimization Application in a Research Environment," NASA TM-1999-209335**

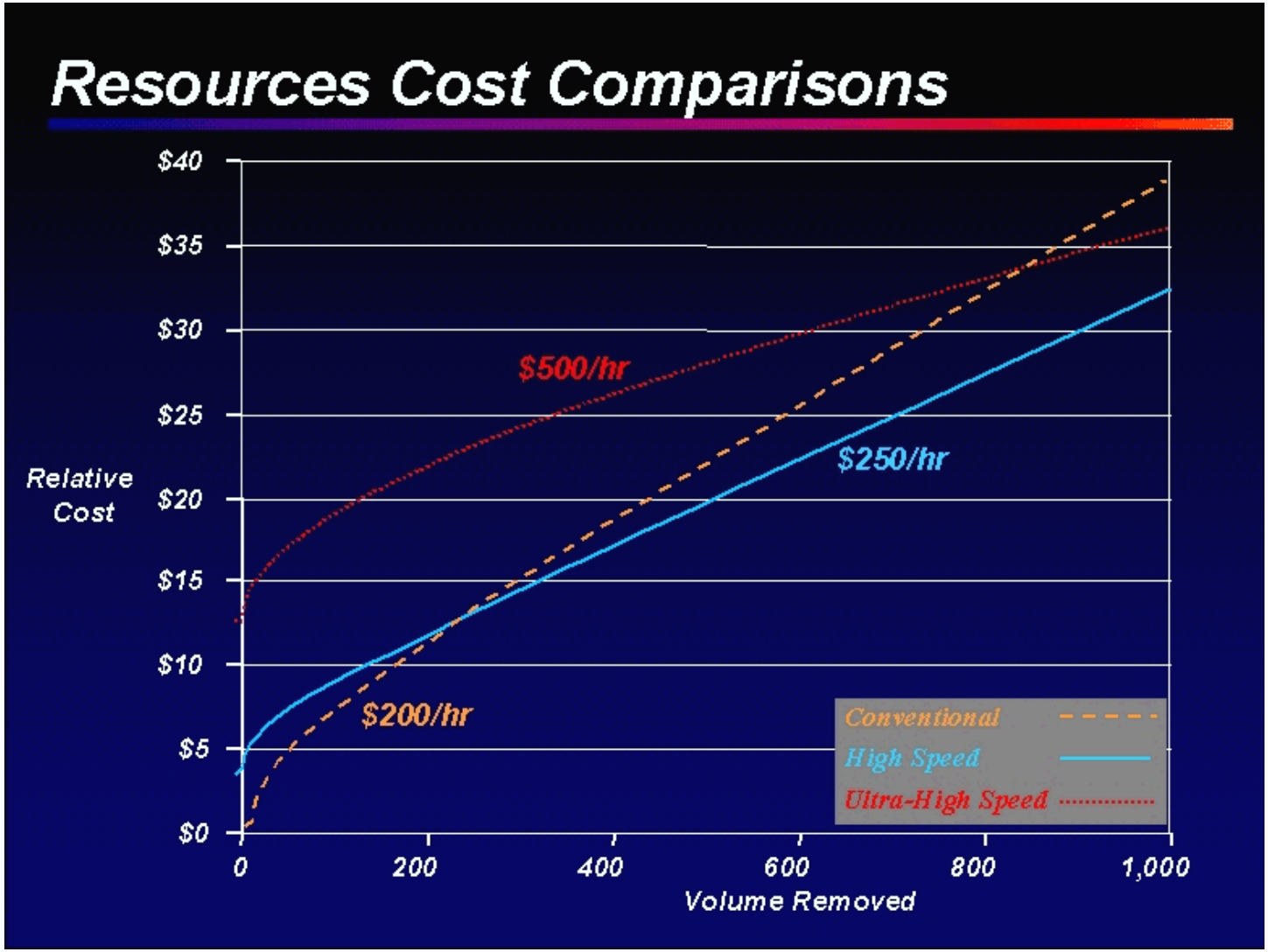
Cost-Performance Optimization

- **Background**
  - **Current cost models use Cost Estimating Relationships (CERs) based on historical data**
  - **Process-based cost models are necessary for reliable cost estimates for unconventional vehicles**
- **Emphasis**
  - **Start with manufacturing cost and extend to life-cycle cost later**
  - **Exploit a 10-year NASA investment in process-based manufacturing cost models**
  - **The resulting commercial software COSTRAN predicts manufacturing cost based on component shape, material choice, manufacturing process, and assembly process**
- **Note:**
  - **For any given system, the pertinent manufacturing processes and parameters must be added to COSTRAN**

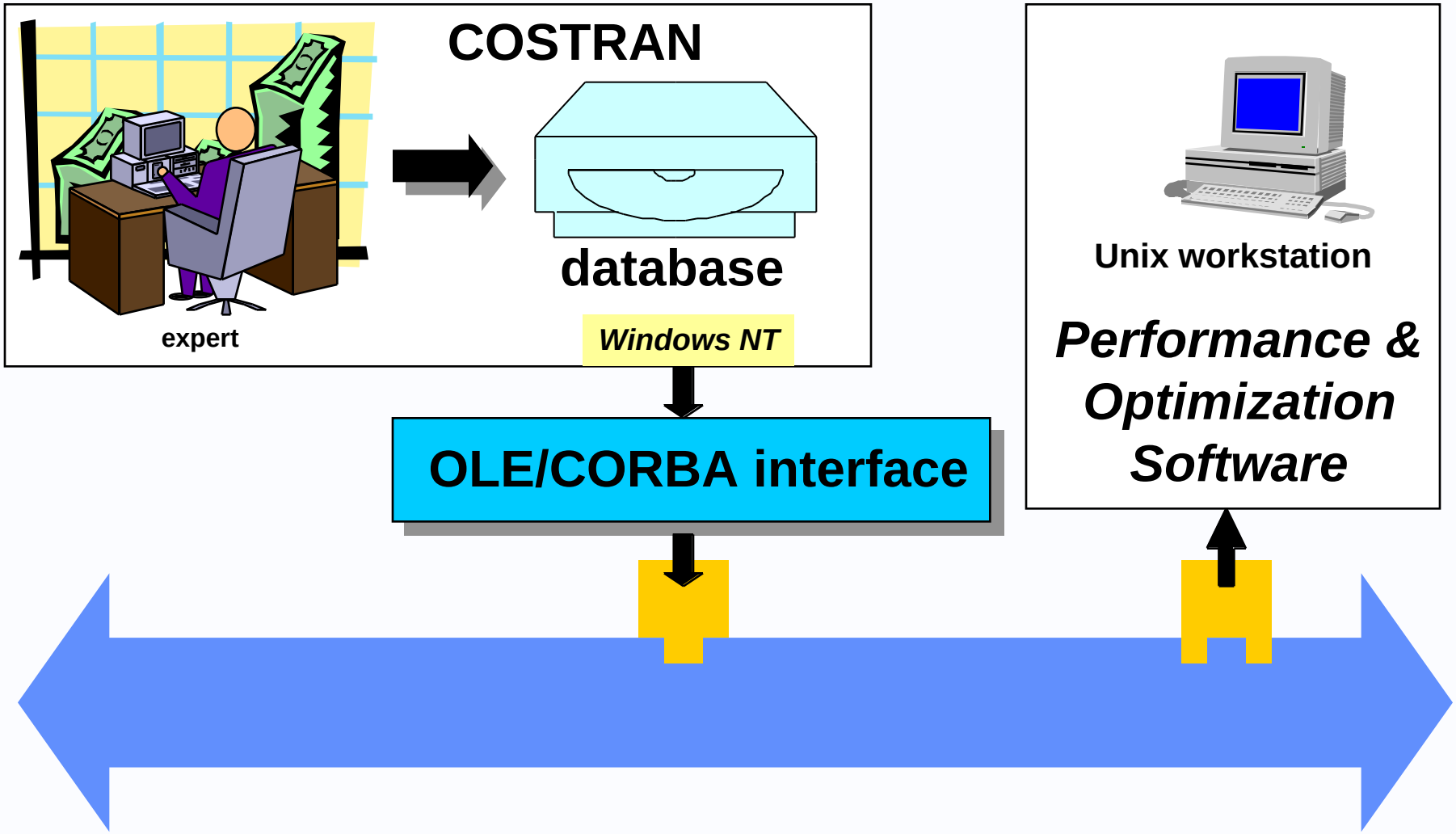
Cost-Performance Issues

- **How does one link Windows-based cost models to Unix-based performance & optimization models?**
- **What information is exchanged between cost and performance models?**
- **Optimization Technology for discrete and continuous variables**

Process-based Cost Model

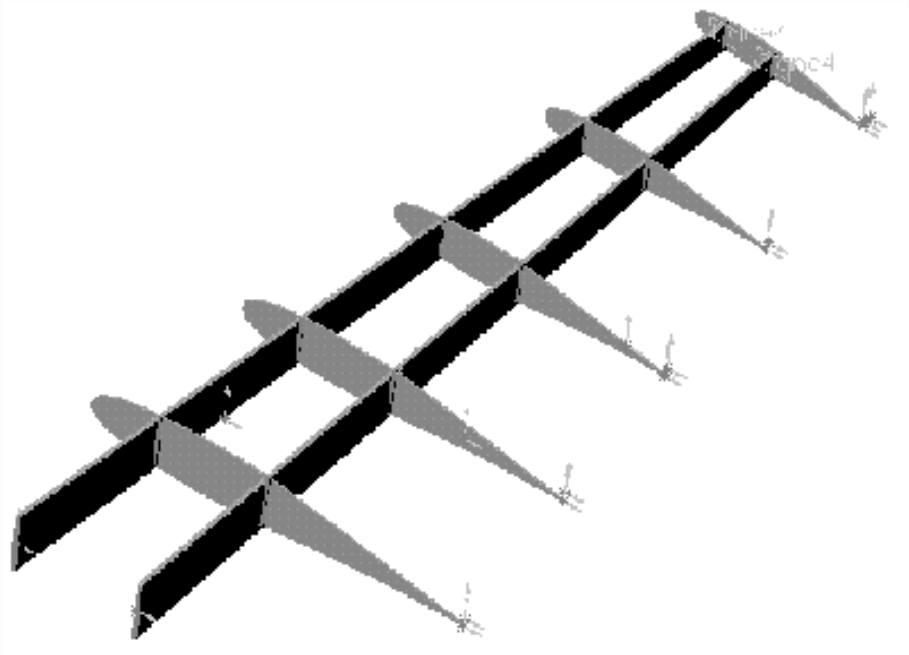


Cost-Performance Computer Linkage

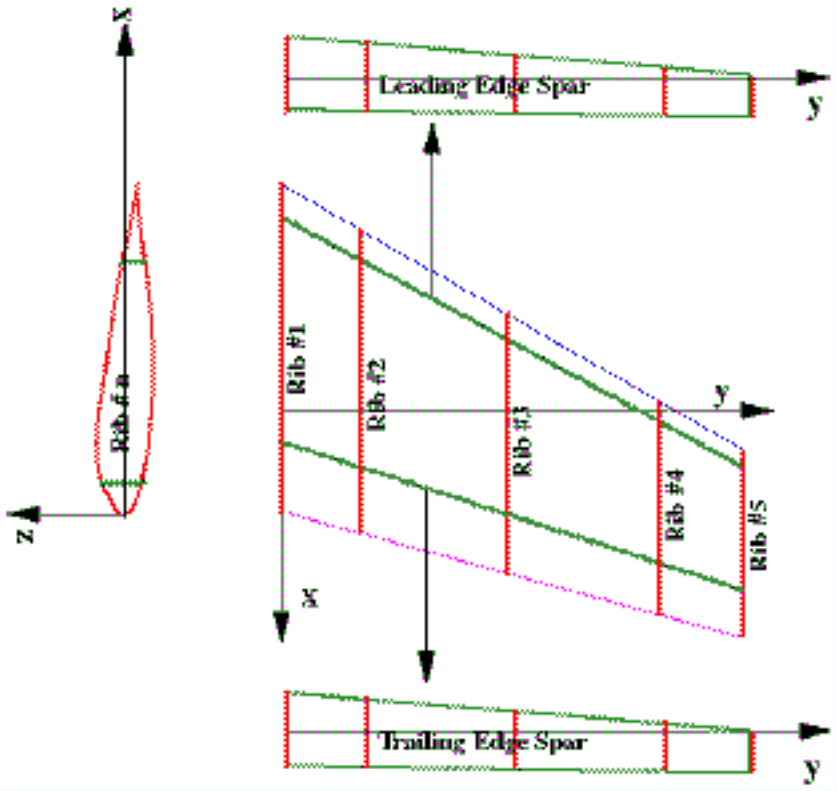


Performance & Cost Models for a Generic Aircraft Wing

Wing Performance Model
(skin not shown)



Parametric Wing Cost Model
(46 design variables)



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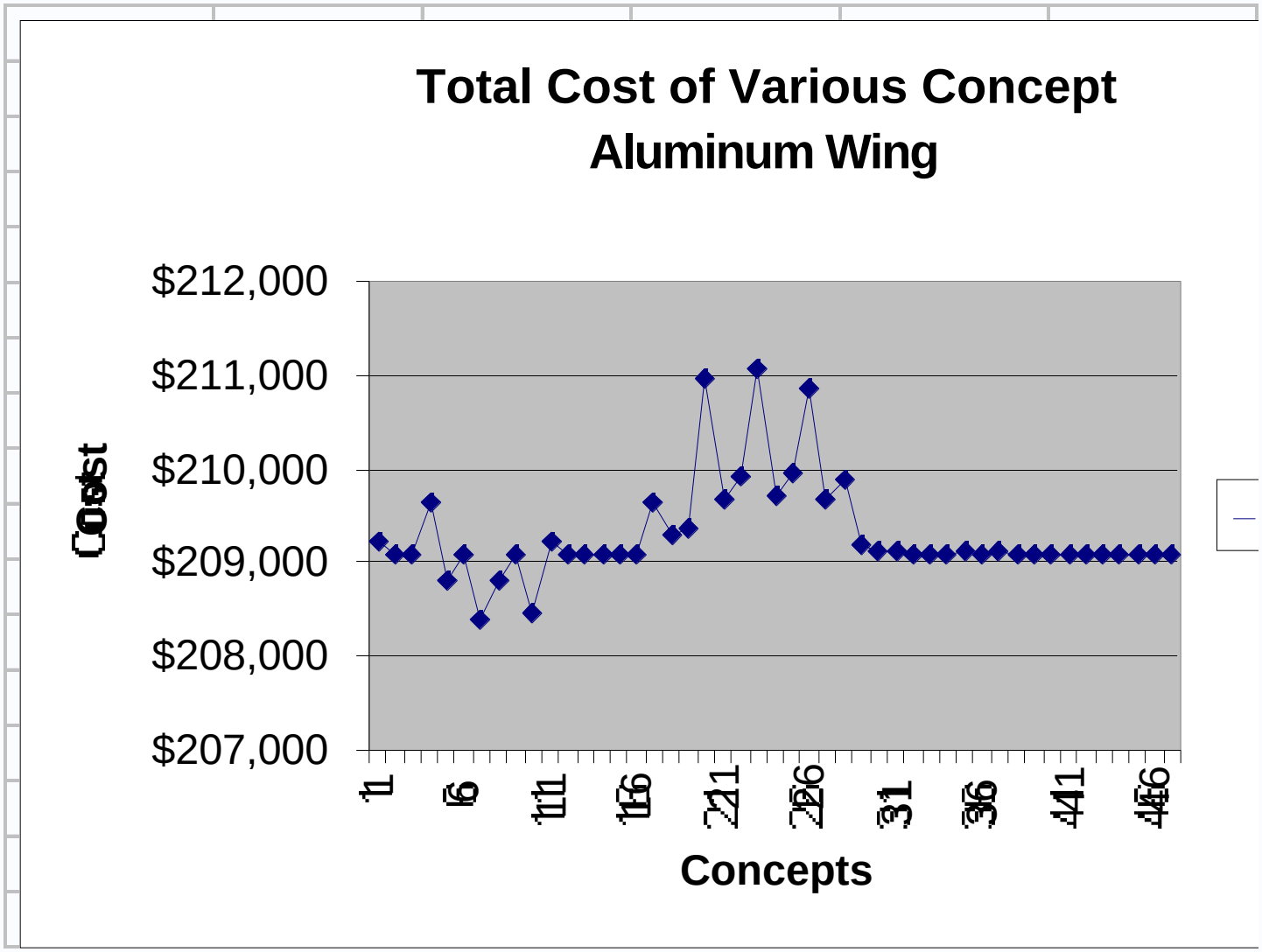
Cost Impact of 5% Changes in Design Variables



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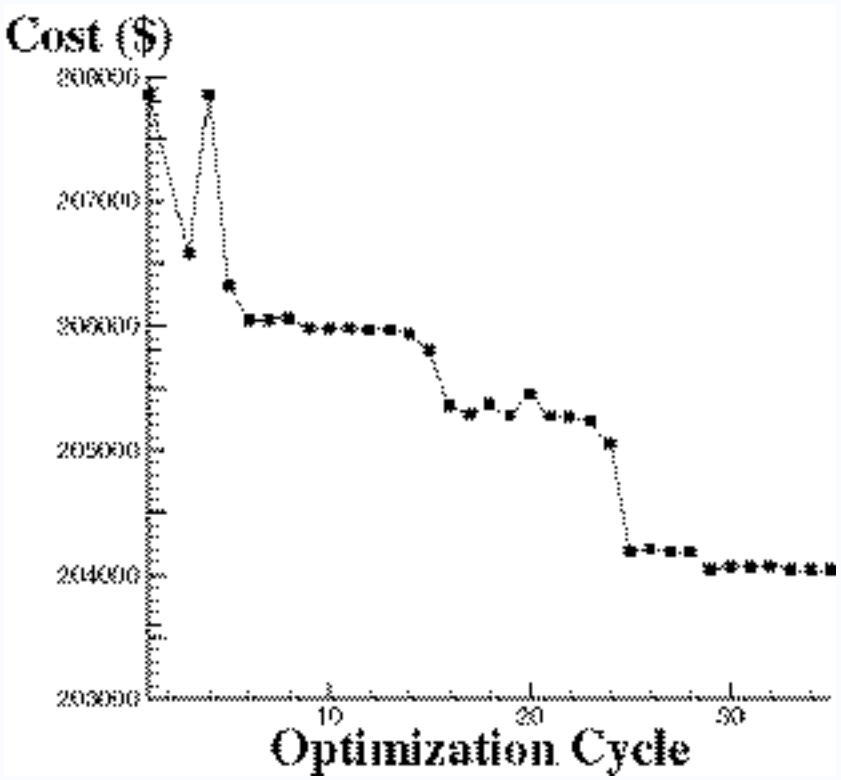
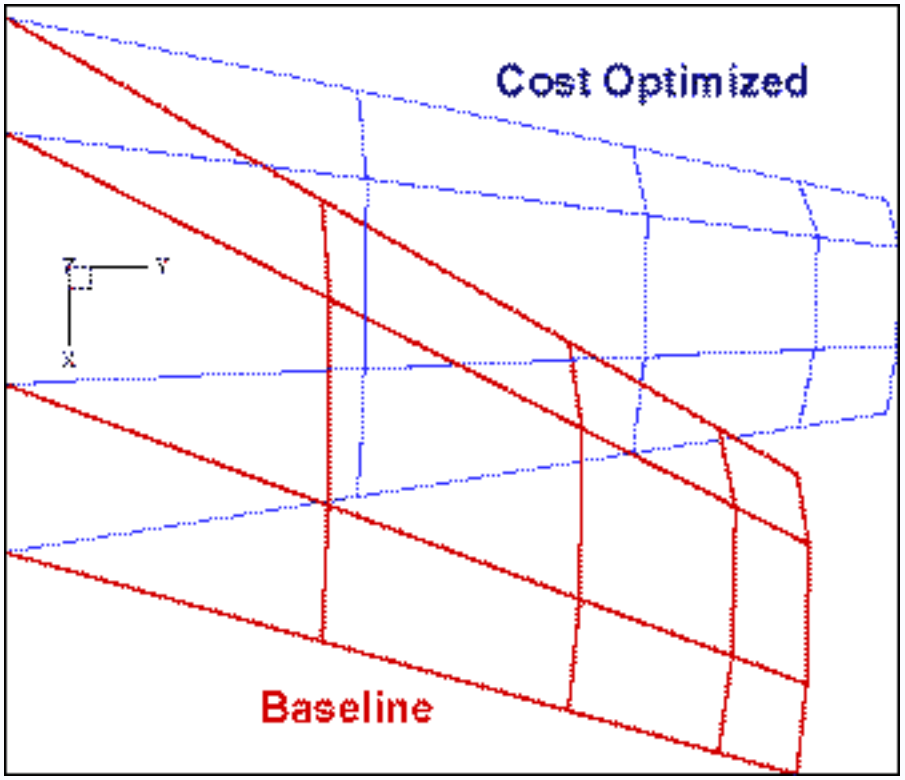
Continuous Optimization Over Wing Shape

Manufacturing Cost History



Initial & Final Planform



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Cost-Performance Publications

- **Process-based Cost Model**
  - **T. Gutowski, *et al*., "Development of a theoretical cost model for advanced composite fabrication", Composite Manufacturing, Vol. 5, No. 4, 1994, pp. 231-239**
  - **M. R. Proctor and S. L. Metschan, "Data Integration and the effect on IPT cost communication," The International Society of Parametric Analysis (ISPA) & The Society of Cost Estimating and Analysis (SCEA) 1998 Joint International Conference and Educational Workshop June 1998**
- **Cost-Performance Optimization**
  - **H. P. Bao and J. A. Samareh, "Affordable Design: A Methodology to Implement Process-based Manufacturing Cost Models Into the Traditional Performance-focused Multidisciplinary Design Optimization," AIAA 2000-4839**

Key URLs

- **MDO Branch Home Page**
  - **http://fmad-www.larc.nasa.gov/mdob/MDOB/**
- **Publications**
  - **…/Publications/pub.index.html**
  - **list of publications since 1994, with many papers available electronically**
- **Conference Presentations**
  - **…/Conference/conf-present.html**
  - **electronic copies of all conference presentations since 1997**
- **Team Dynamics**
  - **…/team-dynamics/team.html**
  - **several in-depth studies of MD teaming issues**
- **MDO Test Suite**
  - **…/mdo.test/index.html**
  - **explanations, code & sample results for MDO problems**